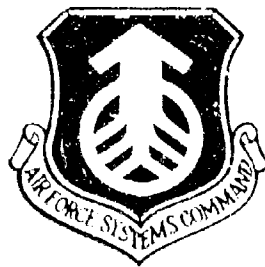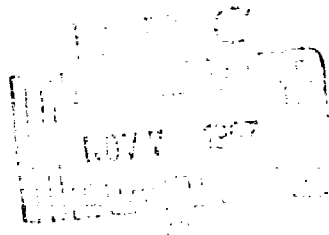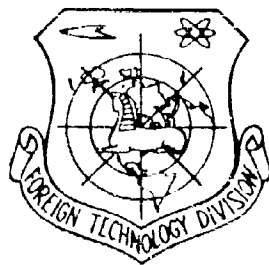# F REIGN TECHNOLOGY DIVISION

REDUCING AERODYNAMIC RESISTANCE HOLES WITH
ANNULAR RIBS AND RECESSES

by

K. I. Khanzhonkov

NOV 1 1967

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ABSTRACT: This article describes means of reducing the aerodynamic resistance of holes with annular ribs and recesses. One way is to make the edge of the opening turned toward the stream rounded. The principle of action of annular fins and recesses are explained and their optimum geometrical dimensions at which input resistance becomes minimum are revealed. Experimental installations and testing methods are described. Test results with both annular fin and annular recess are given and discussed. English Translation: 24 pages. Orig. art. has 19 figures.

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REDUCING AERODYNAMIC RESISTANCE HOLES WITH ANNULAR RIBS AND RECESSES

V. I. Khanzhonkov

As a result of stream compression and subsequent expansion of same behind the opening, the flow of real fluids and gases through openings is usually accompanied by a considerable energy loss. The energy loss is especially great if the input edge of the opening is made sharp. And so, at a sharp input edge for an opening situated in a flat wall of a reservoir, energy loss equals ~2.7 of dynamic pressure of the stream determined by the average velocity in the opening; and for a pipe opening with a sharp input edge, it is equal to the dynamic pressure of the stream.

For the purpose of reducing the input resistance of the edge of the opening turned toward the stream, the opening is made rounded. In this case, when the thickness of the wall, in which the opening is made is small, and as a result of this, it is impossible to realize a rounding of sufficiently large radius, they resort to installation in front of collector openings, assuring smooth entry of the flow. Ordinarily, conical collectors made in the form of a funnel narrowing towards the opening and profiled by the arc of the circumference, or by very complex curves are used, for example, by a lemniscate arc.

Setting up the collectors profiled by smooth curves, the input resistance in the opening can be reduced to 1.5 - 2% of dynamic steam pressure.

In many instances, when the use of conical and straight collectors is difficult for these or any other reasons, and in some instances even impossible, the input resistance in the opening can be substantially reduced by placing close to the input opening, an annular fin or annular recession enveloping the opening.

We will explain the principle of action of these annular fins and recesses, and we will reveal their optimum geometrical dimensions at which input resistance becomes minimum.

Flow in Openings with Annular Fins

We will examine a flowchart of a liquid during the entry into a tube (Fig. 1). When flowing around the input edge, as a result of the presence of componential velocity normally directed towards the axis of the opening, liquid particles are separated from the edge and move over curvilinear trajectories. At first, the stream behind the input opening narrows gradually, then at a certain distance from the opening, the compression of the stream discontinues and stream threads in that section move parallel to the axis of the opening. Next the stream expands, filling up the passing section of the pipe. An annular area — "dead zone", filled with eddies, is formed between the stream and the wall of the pipe. The process of stream separation from the input edge, narrowing of same and subsequent expansion, is accompanied by an unrecoverable energy loss.

The basic fraction of energy losses is bound with stream expansion in the pipe suring the transfer from its narrow section to the wider. Losses due to inner friction in the liquid during stream

narrowing, to friction against the walls of the pipe and to rotation of eddies in the shaded zone, are small and comstitute hundreds of fractions of the total energy loss.
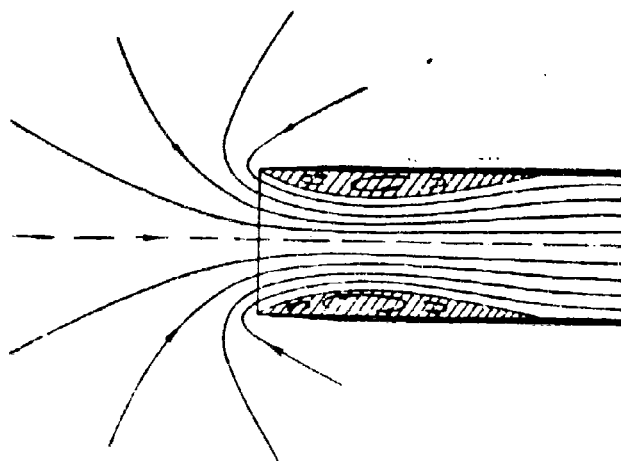

Fig. 1. Entry of liquid into the pipe with sharp edge.

Losses bound with stream expansion can be substantially reduced if we create a preliminary stream compression in front of the opening, in such a degree, that dimensions of the compressed section of the stream would correspond to the dimensions of the input opening. For this purpose annular fins or annular recesses (Fig. 2) can be used. In these cases, the stream runs off from the edge of the fin or recess, and obtaining preliminary compression, tends toward the input opening of the pipe. Eddy masses of the liquid included in the annular space, limited by the surface of the narrowing stream and annular fin (recess), form a certain type of "wet" collector, directing the flow to the input opening of the pipe. Depending upon the ratio of the diameter and length of the fin, a different degree of filling the intake opening of the pipe with the stream can be obtained. Evidently, that such optimum fin dimensions do exist at which the stream fully fills up the intake opening of the pipe, the stream expansion

phenomenon behind the input opening will be brought to nothing, and
the pressure losses at the intake will be minimum. Their magnitude
will be determined basically by the turbulent friction losses,
narrowing the stream by the air included in annular space between fin
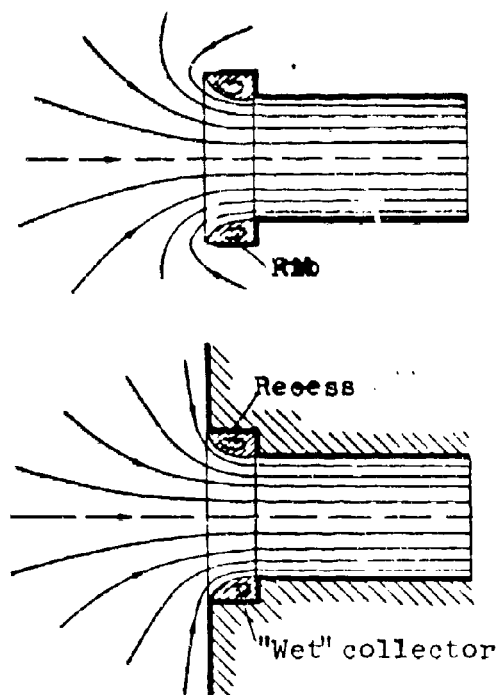(rib) walls and the stream.

Fig. 2. Entry of liquid into pipe with
annular fins and annular recess.

Experimental Installation and Testing Method

The tests were made with a cylindrical pipe with a diameter
d = 122 mm and a wall thickness of 3 mm (Fig. 3). At the input
opening on a section 20 mm long, the wall in the direction to input
opening was gradually made thinner, and at the very input edge, its
thickness was equal to $\delta = 0.3$ mm, which at $\frac{\delta}{d} = \frac{0.3}{122} = 0.0025$ allows
the consideration of the input edge of the opening, sharp in aero-
dynamic ratio.

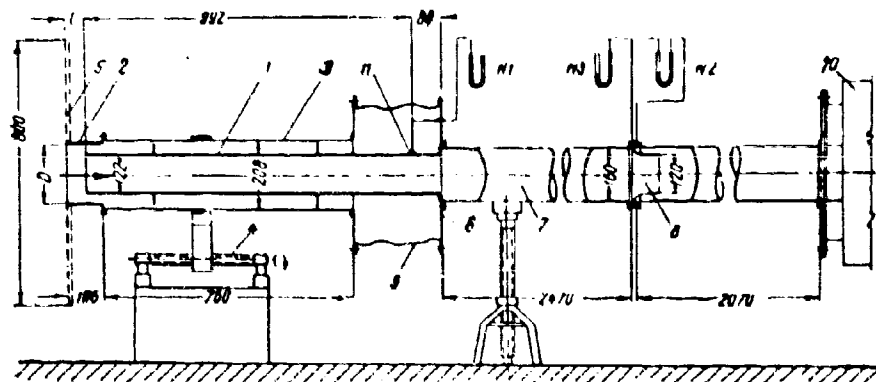FTD-HT-00-371/1+2+4   4

Fig. 3. Scheme of installation to determine the
resistance coefficient of entry into the pipe with
annular fin or recess.
KEY: 1) pipe ϕ 122 mm; 2) annular rib; 3) pipe ϕ
208 mm; 4) coordinator; 5) flat screen; 6) transient
flange; 7) pipe ϕ 160 mm; 8) measuring nozzle; 9)
rubber nipple; 10) air blowing; 11) connecting pipe
for measuring pressure losses; Nos. 1, 2 and 3 are
micro pressure gages.

A selection of cylindrical nozzles, having a wall thickness of
0.3 mm and differing by the diameter value, served to create annular
fins enveloping the input opening of the pipe with sharp edge. Nozzles
with a diameter D = 134, 146, 158, 171, 183 and 195 mm were prepared
for the tests. Change in distance 1 between the cut of the pipe and
and nozzle cut, i.e., change in height of annular fin; was obtained
by displacing the 208 mm in diameter pipe and the nozzle connected
with it along the axis of the basic pipe, with the aid of a special
coordinator, whereby the very basic pipe itself appeared to be
directed for the pipe with a diameter 208 mm. In this case, the
height of the annular fin equalling zero, was obtained when the nozzle
cut and the cut of the pipe lied in one plane.

To obtain an annular recess on the nozzle along side with its
input edge, a flat screen with a diameter of 800 mm was fastened, as
is shown in Fig. 3, by the dotted line.

A pipe with a diameter of 122 mm, with the aid of a transient flange, was attached to a pipe line with a diameter of 160 mm and placed in measuring nozzle with a diameter of 120/160 mm. To this transient flange, by means of a flexible rubber nozzle, a pipe with a diameter of 208 mm with annular fin was attached. Free displacement of the 208 mm pipe relative to the 122 mm in diameter pipe was assured thanks to the rubber nozzle, and the possible air inflow into the input opening of the pipe through the annular channel has been prevented; the annular channel was formed by these pipes. The air flow in the experimental installation was created with the aid of a blower, the insuction opening of which was attached to the 160 mm in diameter pipe.

At the input into the pipe, the magnitude of pressure losses was measured with the aid of a micromanometer No. 1, attached to the connecting pipe with 122 mm in diameter, at a distance of 992 mm from input opening, where the process of readjusting the velocity field behind the input opening for test data can be considered practically finished.

The consumption of air was determined by the pressure differential in front of the nozzle and behind it, measured by micromanometer No. 2. Indications by micromanometer No. 3 registering the pressure in front of the nozzle, was used to determine the volumetric weight of the air flowing through the nozzle; and introductions into the equation of consumption of corresponding corrections, provided by norms after measuring the delivery.

Experiments with the opening in the flat wall were made in line with testing the openings. The opening in the flat wall was made with a diameter d = 360 mm, and it had a sharp intake edge. Annular fins and recesses were made with a diameter D = 416, 440 and 480 mm. The

fins were prepared from sheet steel of a thickness of 0.3 mm in the form of a selection of variable short nozzles of various length. To obtain annular recesses on these nozzles, as well as in the case of tests with a pipe with flat screens, were placed alongside with the input edge of the fin.

The flat wall with opening and annular rib was attached to the rarefaction chamber representing a reservoir with a diameter of 1000 mm and 3000 mm in length. The pressure drop between atmospher and chamber characterized the resistant to flow through of air through the opening. Air delivery and the pertinent average rate of the flow in the opening was determined with the aid of the measuring collector placed between the rarefaction chamber and ventilator, which sucks out the air from the chamber.

The resistance coefficient of entry into the pipe with annular fins or recess was determined by the differential, in total pressures up to and after the input opening

$$\zeta = \frac{p_a - p}{\frac{\rho V^2}{2}} - 1. \tag{1}$$

where p_a — is the pressure in the surrounding space (atmosphere);
  p — is the static pressures in the pipe with a diameter of 122 mm;
  V — is the average rate of flow in the input opening of the pipe, calculated by consumption;
  ρ — density of air.

The input resistance coefficient determined by formula (1), is referred to the area of input opening of the pipe, and it includes the input losses connected with stream compression, as well as friction losses of the stream against the walls of the pipe along the section from the input edge to the point of measuring static pressure p.

The resistance coefficient to outflow from the opening in a flat wall with annular rib or annular recess, was also determined by the differential of full pressures

$$\zeta = \frac{p_a - p}{\frac{\rho V^2}{2}}. \qquad (2)$$

Here p_a — is pressure in the surrounding space from the side of the annular rib;

p — pressure behind the opening in the rarefaction chamber.

This resistance coefficient includes also, pressure losses at the input into the opening, and dynamic pressure losses of the stream at the exit from it.

Test Results

Pipe With Annular Fin

Results of determining the resistance coefficient of entering into the pipe with a sharp edge, in dependence upon the relative length l/d of an annular fin at its various relative diameters D/d, are given in Fig. 4. The negative values of fin length corresponds, to its positions at which the cut of the fin is situated behind the plane of input opening of the pipe, in the direction of flow movement in it. These results were obtained at an Re number $= 3 \cdot 10^5$, referred to the diameter of the pipe.

From the test results, it is evident that without an annular fin, which corresponds to the case of $l/d \leqq - 0.5$, the entry resistance coefficient into a pipe with sharp edge is $\zeta = 1$. In proportion to to the approach of the annular fin to the input opening, the coefficient ζ at first gradually decreases, the more so the greater the diameter of the fin; afterwhich, it gradually and rapidly decreases, whereby the drop in value ζ is faster the smaller the diameter of the fin; then ζ reaches its minimum value and further with the rise in l/d it gradually increases.

It is of practical interest to examine the causes causing such a character in change in coefficient ζ in dependence upon length and diameter of the fin.
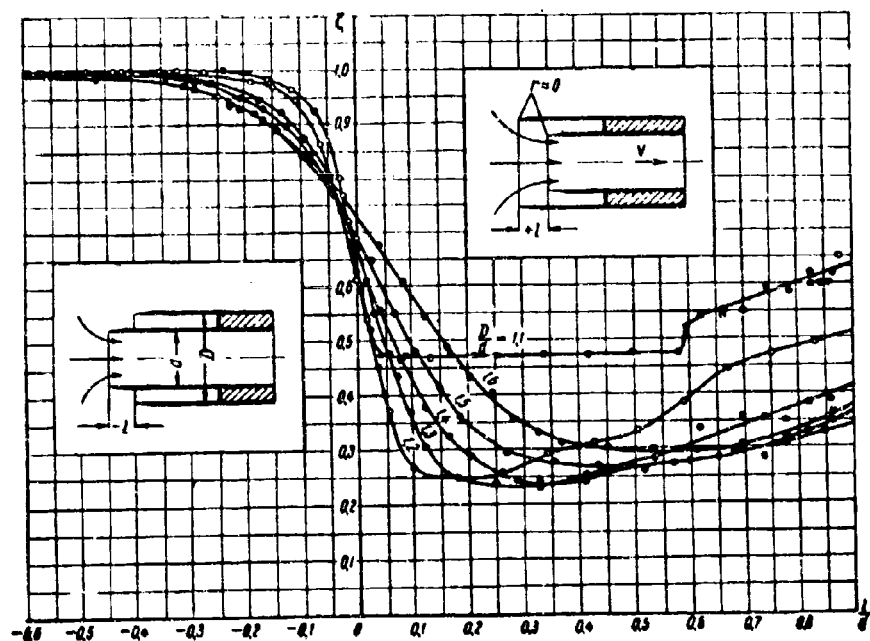
Fig. 4. Resistance coefficient of entry into a pipe with sharp edge and annular fin in dependence upon fin length at various diameters.

At small negative values l/d (from 0.5 to 0) the much greater reduction in the value ζ takes place for openings with small diameter fins. In such a case, at an identical length of the fin, the ratio of the distance between fin and sharp edge of the pipe $\dfrac{D-d}{2}$ to the length l of the fin is smaller for fins of small diameter; as a result of which, the flowing of from the fins streams are directed to the input opening of the pipe at a small angle to the axis of the pipe, and fill up better the input opening of the pipe (Fig. 5, b).

It is interesting to mention, that the smallest value of the coefficient ζ for openings with various fins, is acquired in these cases, when the ratio of the distance between annular fins and sharp edge, to the length of the fin, equals approximately a constant value

$$\frac{D-d}{2l} = \frac{\dfrac{D}{d}-1}{\dfrac{2l}{d}} \approx 0.54.$$

a) $l_1 = l_2$ and $D_2 > D_1$ b) $l_1 = l_2$ and $D_2 > D_1$
$d_0 > d_1$ and correspond- $d_2 < d_1$ and correspond-
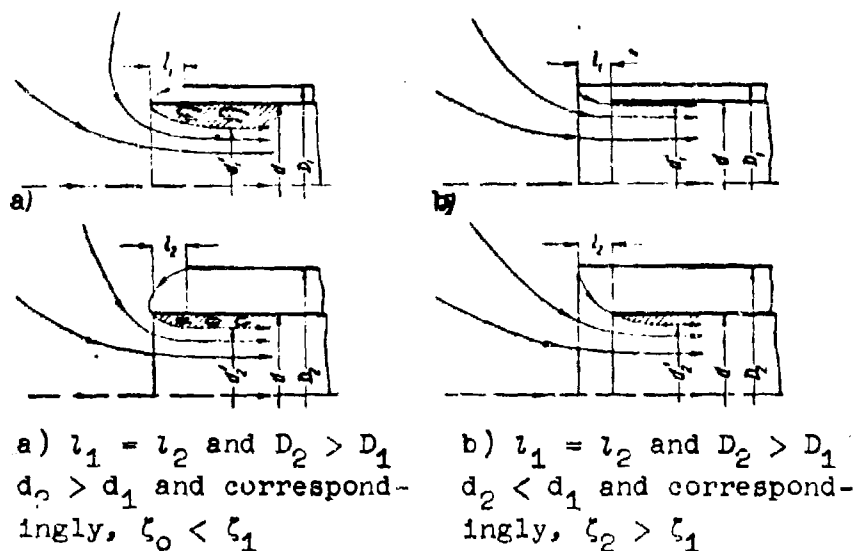ingly, $\zeta_0 < \zeta_1$ ingly, $\zeta_2 > \zeta_1$

Fig. 5 a and b. Effect of length and diameter
of fin on the value of stream at input into
the pipe.

At such a value $\frac{D-a}{2l}$, the stream running of from the edge of an

annular fin, fills up most fully the input opening of the pipe. The

compression phenomenon of the stream disappears behind the opening;

and with it disappear pressure losses bound with the expansion of the

stream. Only pressure losses remain, caused by friction of the

narrowing sections of the stream against the air, which is situated

in the annular space between the stream and annular fin; and the

friction of the stream against the wall of the very pipe on the

section from the input opening to the connecting pipe, by which the

pressure was measured. The smallest input losses take place at an

annular fin with a diameter $D/d = 1.3$ and length $l/d = 0.29$. In this

case, $\zeta = 0.23$.

At a further increase in the length of the annular fin, i.e.,

at $\frac{D-d}{2l} > 0.54$ the resistance coefficient rises gradually because the

sharp input edge of the pipe falls in the expanding section of the

stream; and the stream is forced to bend same (Fig. 6, a) which leads

to a certain compression of the stream behind the opening and a
corresponding increase in coefficient ζ.

Fig. 6. Input into pipe with long fin and fin of
small diameter.

It is necessary to mention a somewhat different nature of the
curve $\zeta = f(\frac{l}{d})$ at D/d = 1.1 in comparison with curves at D/d = 1.2 -
- 1.6 is due to the fact, that at a very small diameter of the
annular fin, the sharp edge of the input opening of the pipe with its
final section, is fully situated in the aerodynamic shadow and on the
process of stream narrowing of the stream flowing off from the edge
of the fin, it almost exerts no effect (Fig. 6, b). At $l/d > 0.6$
the edge of the input in flow of the pipe falls into the expanding
active flow, which as already mentioned, leads to an increase in ζ
coefficient.

For the purpose of improving the inflow smoothness of the stream
into the pipe, its sharp inflow edge was made rectangular, as is shown
in Fig. 7. To obtain a rectangular edge on the pipe with sharp edge,
variable flanges are fitted so that the area of the flange coincides
with the area of pipe cut. The flanges were inserted into an annular
fin with minimum gap, assuring freedom of flange displacement within
the fin at a sufficiently dense adherence of the edge of the flange
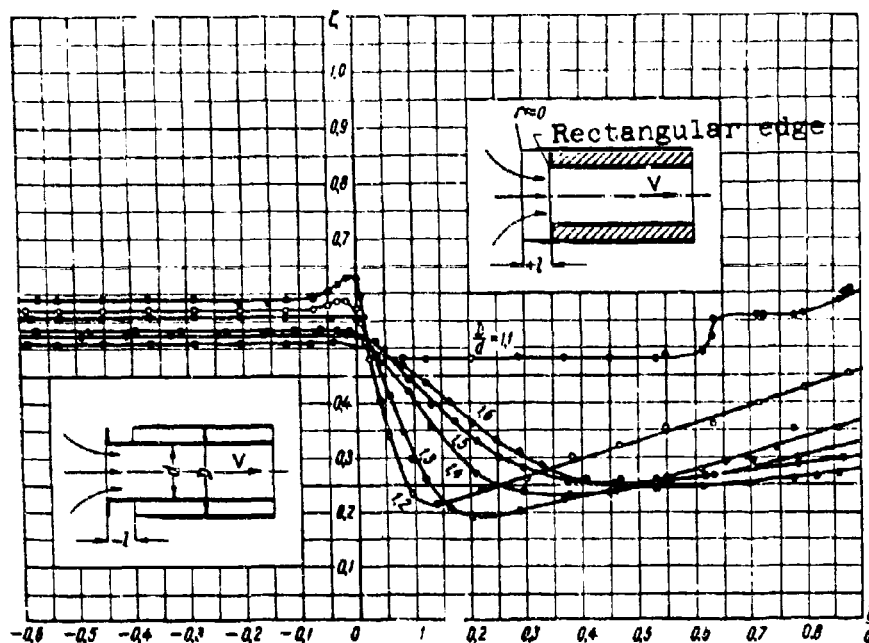to the internal surface of the fin.

Fig. 7. Resistance coefficient of inflow into the pipe with rectangular edge and annular fin, in dependence upon the length of the fin at its various diameters.

The tests have shown that at a rectangular edge, the resistance coefficient of the inflow acquires a somewhat smaller value than at a sharp input edge. The nature of change in dependence $\zeta = f(\frac{l}{d})$ at $\frac{l}{d} > 0$ for a rectangular edge, is preserved in such a way as for the sharp edge. A substantial difference in the value of coefficient ζ takes place at negative values l/d, when the inflow edge of the pipe protrudes outwards from the fin. The presence of a screen at the input into the pipe — flange, making the input edge of the pipe rectangular, reduces the resistance coefficient from $\zeta = 1$ to $\zeta = 0.5$ — — 0.6 at $\frac{l}{d} < - 0.1$. The smallest value the resistance coefficient does acquire at $D/d = 1.3$ and $l/d = 0.24$. In this case, $\zeta = 0.1$.

Another variant improving the smoothness of stream inflow of the stream flowing from the edge of the annular fin into the pipe, served a variant in which the inflow nozzle with sharp edge, was replaced

by a nozzle with input edge rounded off in radius equalling 2% of pipe diameter. Tests were carried out with annular fins of three diameters :   D/d = 1.1, 1.3 and 1.6.

Experiments have shown (Fig. 8) that at an annular fin of small diameter (D/d = 1.1), the coefficient ζ in range $l/d = 0.05 - 0.6$ remains almost the same as at a sharp inflow edge (Fig. 4).   At $l/d \approx 0.6$ when the inflow opening of the pipe falls into the expansion zone of the stream behind the compressed section, roundings off by radius $r/d = 0.02$ of the edge, which improves the inflow conditions, reduces somewhat the pressure losses.   A more noticeable reduction in the resistance coefficient takes place at larger diameters of the annular fin.   And so, at D/d = 1.3, minimum ζ value decreases from 0.23 to 0.21, and at D/d = 1.6 from 0.29 to 0.20.   In this case, the rounded off input edge allows noticeably to reduce the optimum length of the annular fin.
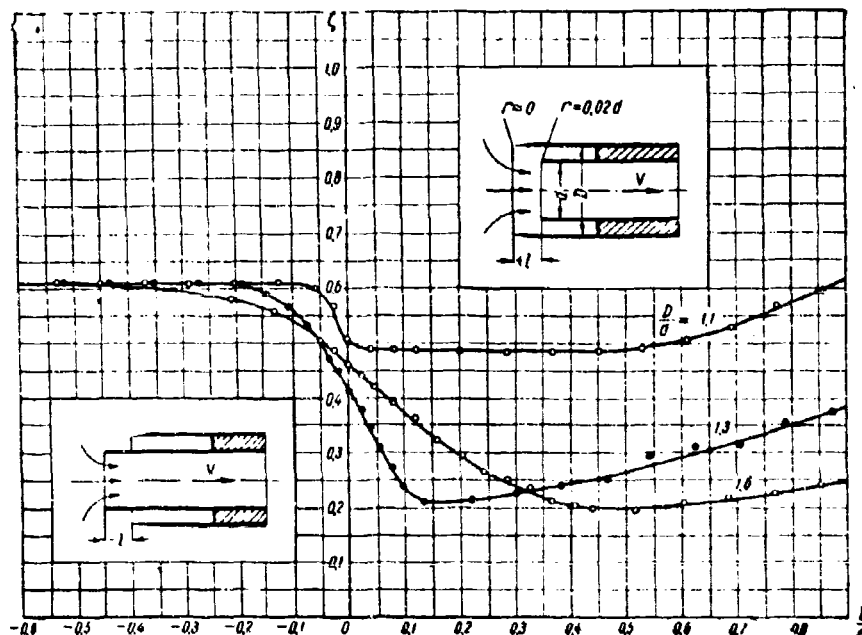

Fig. 8.   Resistance coefficient of inflow into the pipe with rounded edge and annular fin in dependence upon the length of the fin at its various diameters.

In this case, when the inflow opening of the pipe protrudes outwards from the annular fin (at negative values l/d), the resistance coefficient tends to a constant value $\zeta = 0.61$, which corresponds to a free entry into the pipe with edge rounded off by a radius $r/d = 0.02$.

Pipe With Annular Recess

Results of testing the input into a pipe with sharp, rectangular and rounded off input edges in the presence of an annular recess, are given in Fig. 9, 10 and 11 respectively.
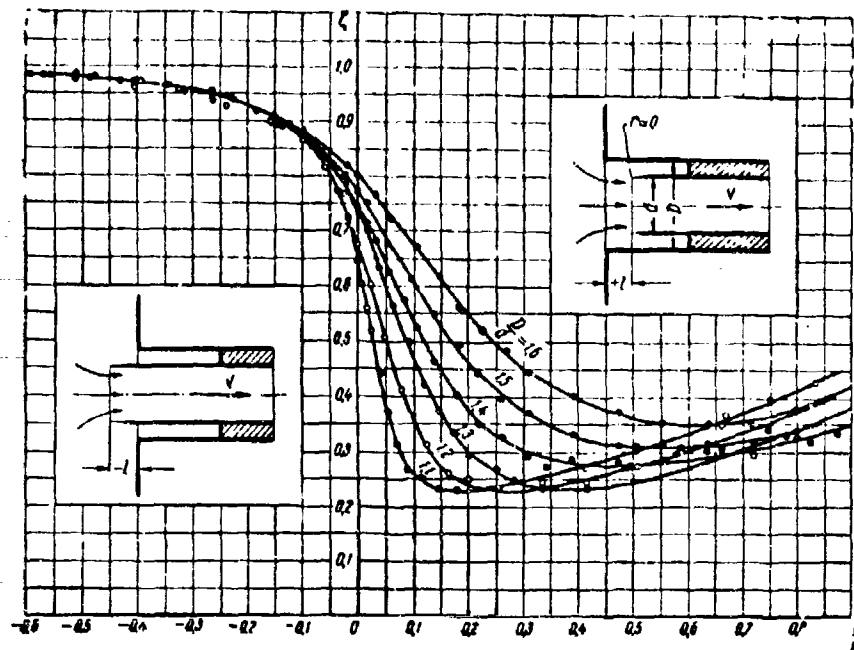

Fig. 9. Resistance coefficient of inflow into the pipe with sharp edge and annular recess in dependence upon the height of the recess at its various diameters.
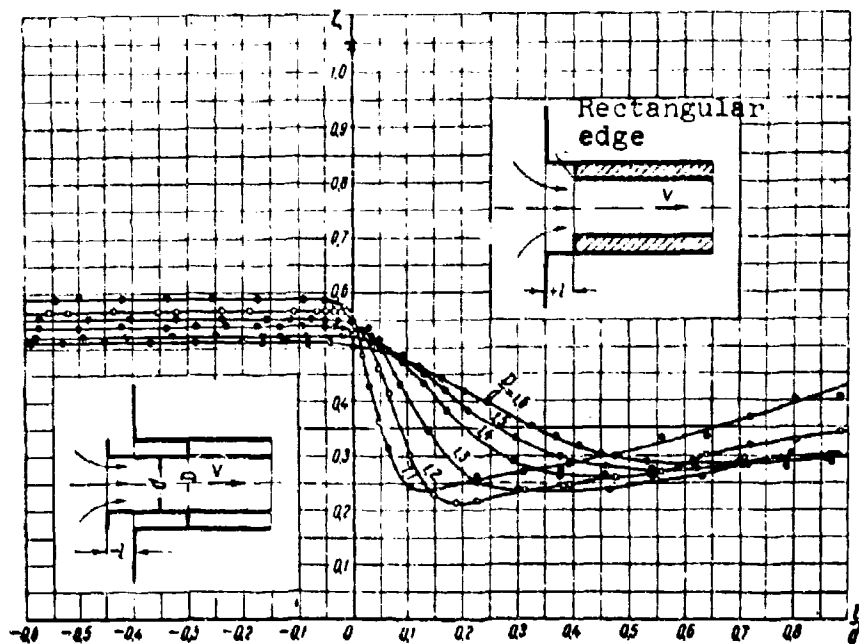
Fig. 10. Coefficient of the resistance of the input into a tube with rectangle edge and with ring offset as a dependence of the depth of the offset in the presence of various diameters.
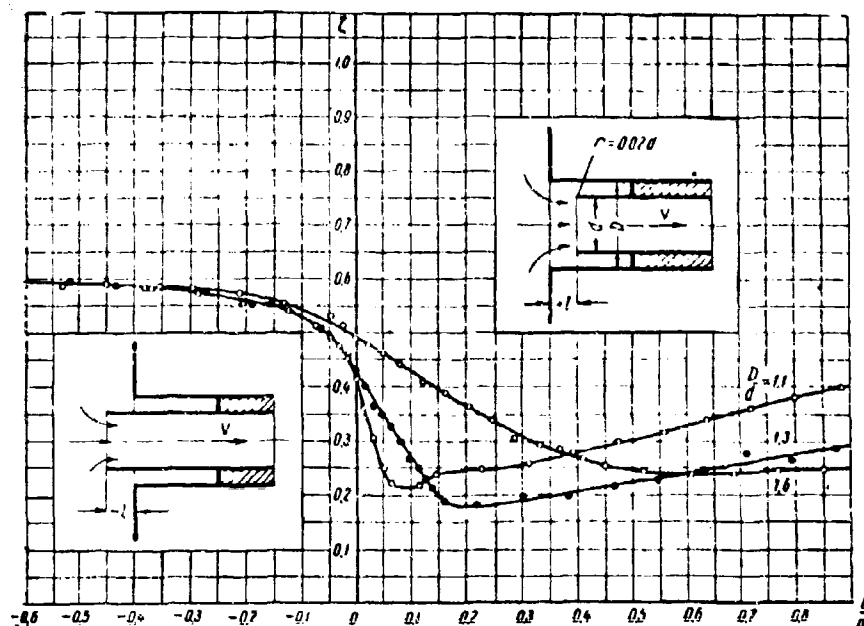

Fig. 11. Resistance coefficient of entry into the pipe with rounded edge and annular recess in dependence upon the length of the fin at its various diameters.

A comparison of graphs, shows that the nature of change in dependence $\theta = f(\frac{l}{d})$ at an identical form of the pipes input edge, for annular fins and annular recesses is ananogous. The difference takes place only for curves $\zeta = f(\frac{l}{d})$ at D/d = 1.1. As already mentioned, the inflow edge of the pipe in a range of l/d = 0.05 - 0.60 is situated in the aerodynamic shadow and on the process of stream narrowing, flowing off from the edge of the fin, exerts almost no effect. The resistance coefficient in this range independently from the form of the input edge of the pipe, remains constant and equal to ζ = 0.47 - 0.48. In the case of an annular recess thanks to the screen, a less sharper turn of the stream near the edge of the recess is assured. The compression phenomenon of the stream weakens, and the input edge of the pipe comes in contact with the active stream. The result of reaction of the input edge of the pipe with the stream appears to be a noticeable reduction in resistance coefficient in the range of changes l/d = 0.05 - 0.06 at D/d = 1.1.

Annular recesses as well as annular fins, substantially reduce pressure losses at the input of the stream into the pipe. Characteristic to that at an annular recess, appears to be this circumstance, the minimum input resistance is observed at a substantially greater length of the recess l/d, than at an annular fin of the very same diameter.

The above given resistance coefficients for the input into the pipe with annular fins and recesses, characterize general pressure losses, consisting of local losses connected with flow separaterion from the input edge of the opening and its subsequent expansion in the pipe, and pressure losses caused by friction of the flow against the walls of the pipe along the section from the input opening to the

section, in which pressure was measured during the experiment. In this way, the coefficient of general pressure losses at the input is

$$\zeta = \zeta_{_M} + \zeta_{_{\tau p}}.$$

In order to determine the value of local input losses, it is necessary to deduct the friction losses from the general losses. To reveal by an experimental way, the actual value of pressure losses to friction appears to be impossible. The fact is, that the surface ratio of pipe walls flushed by the active stream, and the surfaces of pipe walls coming in contact with the eddy area, appears to be a variable value depending upon the dimensions of the annular fin and the degree of sharpness of the input edge of pipe opening. The determination of this ratio is bound with greater experimental difficulties. But in this case, if they would be overcome, the nature is still complicated by another, which remains unknown as the value of the friction coefficient of circulating flows against the wall of the pipe; as well as the friction coefficient of the active stream, the rate of which on the constant section with the wall of the pipe, is variable. Consequently, the value of the local resistance coefficient can only be approximately determined.

No doubt, the value of friction losses becomes small in comparison with local input losses, at a sharp compression of the stream behind the input opening of the pipe, when the area with the circulation streams is great. In this case, the value of the local input resistance coefficient is close to the value of the general resistance coefficient and can be practically assumed to be

$$\zeta_{_M} \approx \zeta.$$

At a small stream compression behind the opening or at complete absence of compression, when the stream over the entire extension of

the experimental sectionof the pipe comes in contact with the wall, the friction losses caused by friction of the stream, becomes comparable with the local input losses, and it is not permitted to disregard same.

If the friction coefficient λ_1 is conditionally adopted, the pipes on this section equaling the friction coefficient λ for the section of the pipe with fully developed turbulent flow, i.e.,

$$\lambda_1 = \lambda = \frac{0,3164}{\sqrt[4]{Re}},$$

then the pressure loss coefficient to friction can be evaluated by the value

$$\zeta_{\tau p} = \lambda_1 \frac{L}{d}, \tag{3}$$

where L-length of pipe section from the input opening to the connecting pipe, where the pressure was measured.

Then applicable to conditions of our experiments

$$\lambda_1 = \frac{0,3164}{\sqrt[4]{Re}} = \frac{0,3164}{\sqrt[4]{3 \cdot 10^5}} = 0,0135$$

and

$$\zeta_{\tau p} = \lambda_1 \frac{L}{d} = 0,0135 \frac{992}{122} \approx 0,11.$$

The local resistance coefficient for input into the pipe with annular fin (recess)

$$\zeta_{u} = \zeta - \zeta_{\tau p} = \zeta - 0,11. \tag{4}$$

This formula can be used in cases when stream compression behind the input opening of the pipe is very small or is totally absent, i.e., in cases of constructing annular fins or recesses optimally small or close to these dimensions at the pipe input.

In Figs. 12 and 13 minimal coefficients of local input resistance into the pipe with annular fins and recesses at different form of input edge of the pipe are given, and corresponding to them optimum lengths of the fins (recesses) in dependence upon fin (recess) diameter.

These dependences were formulated on the basis of test results represented in Figs. 4-11, with consideration of pressure losses due to friction against the wall of the pipe, calculated by formula (4). On these graphs, it is clearly evident that the device of rectangular or rounded edges at the input into the pipe in comparison with a sharp edge, allows essentially to reduce the optimum length of the fin (recess) at a certain reduction in local input resistance coefficient.
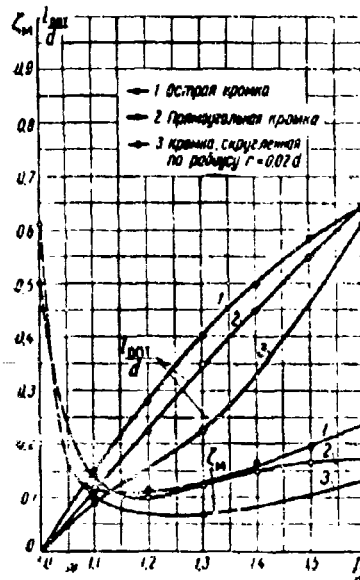

Fig. 12. Minimum local input resistance coefficients into the pipe with annular fin and corresponding to them, optimum lengths of annular fin.   1 — Sharp edge; 2 — rectangular edge; 3 — — edge rounded by radius r = 0.02 d.
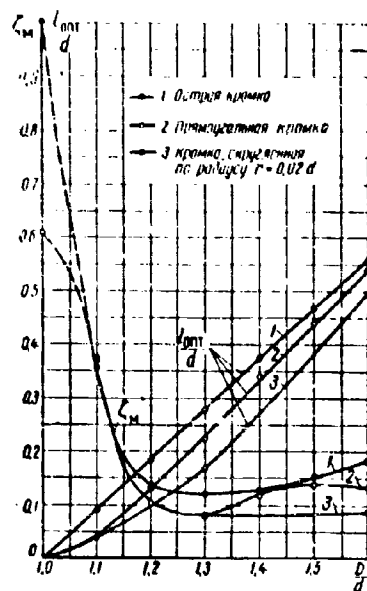
Fig. 13. Minimum local resistance coefficients of entry into the pipe with annular recess and corresponding to them, optimum lengths of annular recess.
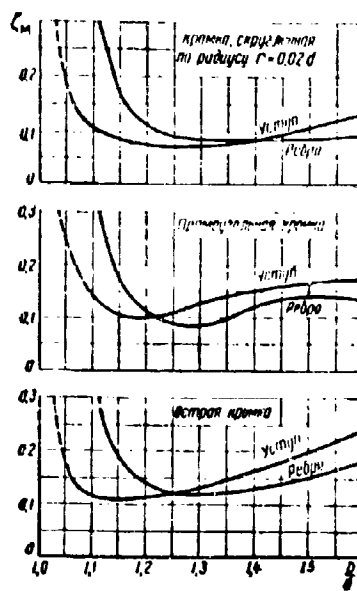

Fig. 14. Minimum local resistance coefficients for annular fins and recesses at an identical form of input edge of pipe.
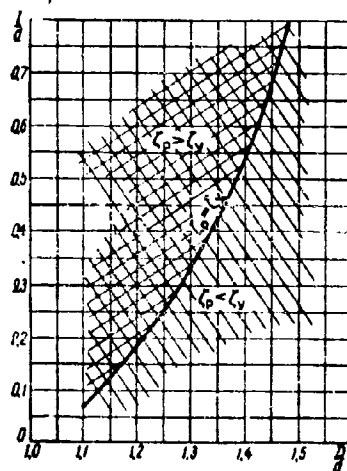

Fig. 15. Zones of suitable application of annular fins and recesses at their identical overall dimensions for input into pipe with sharp edge.
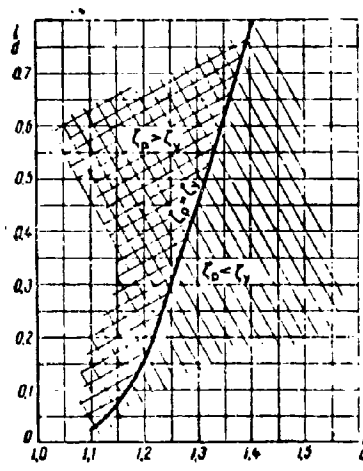

Fig. 16. Zones of suitable application of annular fins recesses at their identical overall dimensions for input into pipe with rectangular edge.

In Fig. 14, curves of minimum local resistance coefficients for annular fins and recesses at identical form of input edge of the pipe are compiled. Using this graph, it is easy to determine the convenience of applying an annular fin or recess in dependence upon their diameters, if in this case, the selection of fin or recess length is not limited. And so, for example, for a sharp input edge of the pipe at $D/d < 1.25$ by the arrangement of the recess, smaller pressure losses at the entry into the pipe can be obtained than at a fin; at $D/d > 1.25$, on the contrary, the presence of an annular fin at input allows the obtainment of smaller pressure losses in comparison with the recess.

At identical overall dimensions of fin and recess preferably of this or any other arrangement, it depends upon the value of its relative diameter D/d and relative length l/d. In Fig. 15, on the basis of processing the test results represented in Fig. 4 and 9, a curve is given splitting two zones, one of which (the upper) characterizes these values D/d and l/d at which the application of annular recesses is convenient and the other (lower) — annular fins at input into the pipe with sharp edge. The very curve determines the interrelation between D/d and l/d, at which the resistance coefficients ζ for fin and ζ_y for recess have identical values. In Fig. 16, an analogous curve with zones of convenient application of annular fins and recesses for the case of input into a pipe with rectangular edge is given. This curve was formulated by test results depicted in Figs. 7 and 10.

The use of these curves allows the rapid evaluation of the advisability of using fins or recesses at their given overall dimensions.

The value of the local resistance coefficient at given D/d and l/d in this case is determined respectively by graphs depicted in Figs. 4, 7, 9 and 10, with introduction of a correction considering

pressure losses from friction of the flow against the walls of the pipe in conformity with formula (4).

Opening in Flat Wall with Annular Fin and Annular Recess

The arrangement of annular fin, or recess at the input into the opening situated in a flat wall, allws even more sharply, the reduction of pressure losses at outflow in comparison with loss reduction at the entry of the flow into the pipe. For an opening without annular fin or recess ($l/d = 0$), the resistance coefficient of outflow $\zeta = 2.7$ (Fig. 17 and 18).

In ratio to the increase in length of fin or depth of recess l/d, the coefficient ζ sharply decreases; at a certain l/d value it reaches its minimum and then with the rise of l/d, it increases gradually. Experiments have shown, that at an arrangement of a fin with a diameter $D/d = 1,222$ and length l/d 0.25 the coefficient $\zeta = 1.15$; at an arrangement of an annular recess with a diameter $D/d = 1.156$ and depth $l/d = 0.2$ the coefficient $\zeta = 1.18$, i.e., it decreases by approximately 2.3 times. We will mention, by the way, that in an ideal case when the phenomenon of stream compression behind the opening is fully absent, and the flow is without friction, pressure losses are equal to the dynamic pressure of the stream, i.e., $\zeta = 1$.

At small relative diameters D/d of the annular fin, a sharply expressed minimum of pressure losses takes place (curve $\zeta = f(l/d)$ at $D/d = 1.156$). The rapid growth of ζ at an increase in l/d ratio is explained in this case by the fact, that the edge of the opening in the wall falls into the aerodynamic shadow created by the fin, as a result of which the suction effects of the annular zone, limited by the fin, opening edge and surface of the stream, is considerably reduced and the stream passing the edge of the opening continues

being compressed behind the opening. This leads to a sharp rise in ζ coefficient with an increase in l/d.

In Fig. 19 the effect is shown of the annular fin on the nature of velocity distribution in the stream beyond the opening. Experiments were carried out with a fin with a diameter $D/d = 1.222$ and length $l/d = 0.25$, i.e., with dimensions at which is observed a minimum value of the resistance coefficient $\zeta = 1.15$. The velocity fields were measured with a Pitot tube in three sections, remote from the plane of the opening at distances of 0.028 d; 0.5 d and 1.0 d. Tests have shown that the arrangement of the fin considerably improves the uniformity of velocity distribution by sections. The ratio of maximum velocities in sections to the average output velocity of the stream from the opening decreases from $V_m/V = 1.62$ to $V_m/V = 1.1$. A similar improvement in uniformity of velocity distribution is observed also at input into the pipe with annular fin or recess.
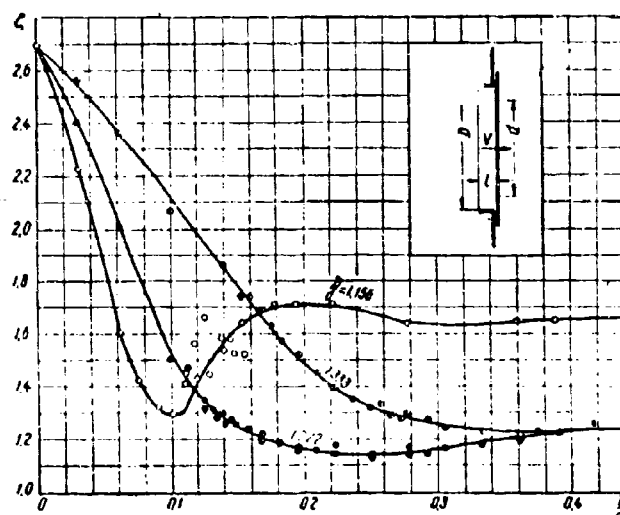

Fig. 17. Resistance coefficient of opening with annular fin in dependence upon height of the fin at its various diameters.
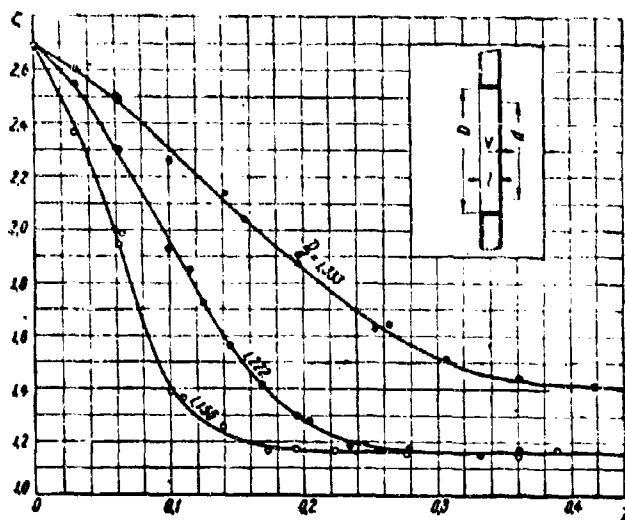
Fig. 18. Resistance coefficient of opening with
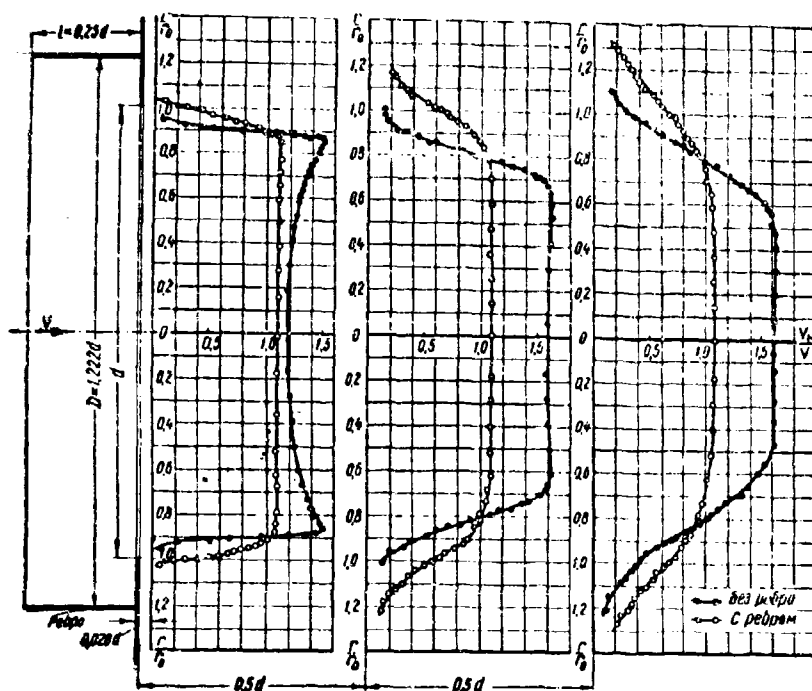annular recess in dependence upon depth of recess
at its various diameters.

Fig. 19. Velocity distribution in the stream,
coming out from the opening with annular fin
and without it.